Hydrogen Passivation in n- and p-Type 6H-SiC

F. REN
Lucent Technologies, Bell Laboratories, Murray Hill, NJ 07974

J.M. GROW and M. BHASKARAN
New Jersey Institute of Technology, Newark, NJ 07102

R.G. WILSON
Hughes Research Laboratories, Malibu, CA 90265

S.J. PEARTON
University of Florida, Gainesville, FL 32611

Hydrogen passivation effects are found to be much more prevalent in p-type 6H-SiC relative to n-type material. Reactivation of passivated B accepters occurs at ~700°C, corresponding to a reactivation energy of ~3.3 eV. This is much higher than for passivated acceptors in Si, where reactivation occurs at ≤200°C. The incorporation depth of 2H from a plasma at 200°C is ≤0.1 μm in 30 min, corresponding to a diffusivity approximately two orders of magnitude lower than in Si at the same temperature. The average energy of ions in the 2H plasma has an influence on the peak concentration of incorporated deuterium and on its diffusion depth.

Key words: Hydrogen, passivation, SiC

INTRODUCTION

There has been a resurgence in interest in SiC in recent times. The main applications are for high temperature/high power electronics, including metal oxide semiconductor field effect transistors, millimeter wave devices, and junction field effect transistors.1-7 Blue light-emitting diodes based on SiC are commercially available,8 although they face stiff competition from devices based on GaN which has a direct bandgap and therefore higher optical output.9 Hydrogen is a component of virtually every gas or chemical involved in the growth and processing of SiC. For example, silane (SiH₄) and propane (C₃H₈) diluted with hydrogen can be employed as the sources for SiC epitaxial growth,10 and alternative organo-silanes are also gaining attention.11 Boron doping can be accomplished with diborane (B₂H₆) diluted with hydrogen.10 The extremely good chemical stability of SiC requires that dry etching be employed for patterning, and hydrogen is generally added to the plasma chemistry to avoid rough surfaces.12-14 High temperature (1500–1700°C) annealing in H₂, followed by quenching to room temperature produces hydrogen passivation (up to ~75% decrease in carrier density) in both n-type (N-doped) and p-type (Al,B) SiC.15 This effect was reversed by subsequent annealing in He at the same temperatures.15 Annealing at 1700°C of chemical vapor deposited 6H-SiC epilayers increased the net hole concentration by a factor of approximately three and was accompanied by outdiffusion of hydrogen,10 and was consistent with residual passivation of B acceptors in the as-grown films. Theoretical studies of the properties of hydrogen in SiC have suggested that a tetrahedral interstitial site is the lowest energy site in undoped 3C-SiC, with a barrier to diffusion to the bond centered site of 1.5 eV.16-18 In 6H-SiC, it was suggested that another interstitial position (the R-Site) was the lowest energy site, with the diffusivity being slightly slower than in Si.16-18

Thus, unintentional incorporation of hydrogen may occur at virtually any stage during the growth and
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MICROWAVE COUPLING AND TUNING

Fig. 1. Schematic of reactor employed for deuteration of SiC.

The hydrogenation effects. In Si, acceptor passivation is a more efficient and thermally stable process than donor passivation because hydrogen occupies a more strongly bound bond-centered position between the acceptor and the nearest-neighbor Si atom, whereas in n-type material the hydrogen is at a less strongly bonded, anti-bonding interstitial position. It is, therefore, also of interest to examine differences in susceptibility of hydrogen passivation of n- and p-type material.

In this paper, we report on an investigation of passivation of donors and acceptors in bulk SiC exposed to electron cyclotron resonance H\textsubscript{2} plasmas. We find that acceptor passivation is much more efficient under these conditions than donor passivation. The ion energy during plasma exposure has a strong influence on the passivation effectiveness. Reactivation of the acceptors occurs at ≤700°C.

EXPERIMENTAL

Bulk 6H-SiC substrates from Cree Research were employed in these experiments. The n-type wafer was doped to 1.5 × 10\textsuperscript{19} cm\textsuperscript{-3} (N dopant) while the p-type sample was doped to 2.5 × 10\textsuperscript{18} cm\textsuperscript{-3} (Al dopant). The Si face of each sample was used for the plasma processing and subsequent analysis.

The samples were exposed to H\textsubscript{2} plasmas in a Plasma Therm SLR 770 reactor, shown schematically in Fig. 1. The plasma is generated in a Wavemat (Model 4400) low profile ECR source (2.45 GHz) at 500 W forward power and a pressure of 10 mTorr. Without any additional biasing of the sample, the average ion energy in the discharge is ~25 eV, with an ion density of ~3 × 10\textsuperscript{14} cm\textsuperscript{-3}. The deuterium neutral density is 3 × 10\textsuperscript{14} cm\textsuperscript{-3} at this pressure. In some cases, 150 W of power (13.56 MHz) was applied to the sample position to increase the incident ion energy to ~175 eV. We have previously found in GaAs that this can dramatically increase the incorporation depth of deuterium. Typical plasma exposures were 30 min, with the sample held at 300°C. Subsequent annealing at 500 or 700°C for 1 min was carried out under a N\textsubscript{2} ambient in a Heatpulse 410T furnace. The atomic profile was measured in all samples using a Cameca IMS 4f system, using a Cs\textsuperscript{+} ion beam. The D\textsubscript{2} concentrations were quantified using ion implanted standards, while the depth scales were established from stylus profilometry of the sputtered analysis craters. Current-voltage (I-V) measurements using stainless steel probes were used to measure the breakdown voltages of the samples for both polarities of voltage. We find this is a simple and effective method for gauging the effect of process parameters on the near-surface electrical properties of SiC, since almost identical breakdown voltages are obtained to those with evaporated Ni contacts.

RESULTS AND DISCUSSION

Figure 2 shows secondary ion mass spectrometry (SIMS) profiles of H\textsubscript{2} in n-type SiC after exposure to the H\textsubscript{2} plasma, and after subsequent annealing at...